# TARDEC

# Technical Report

**No. 13614**

## Improved Antifreeze for Combat/Tactical Vehicles



**December 1994**

**By Dwayne Davis**
**USA Tank Automotive Command**
**Mobility Technology Center Belvoir**





U.S. Army Tank-Automotive Command
Research, Development and Engineering Center
Warren, Michigan 48397-5000

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
December 1994

**3. REPORT TYPE AND DATES COVERED**
Final Aug 1989 - October 1993

**4. TITLE AND SUBTITLE**
Improved Antifreeze for Combat/Tactical Vehicles (U)

**5. FUNDING NUMBERS**
PE 0602786A
PR IL762786AH20
TA 12
WU DA0A4626

**6. AUTHOR(S)**
Dwayne Davis

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
U.S. Army Tank-Automotive RD&E Center
Mobility Technology Center, Fuels & Lubricants Division
ATTN: AMSTA-RBF
Fort Belvoir, Virginia 22060-5606

**8. PERFORMING ORGANIZATION REPORT NUMBER**
TARDEC-TR-13614

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Distribution unlimited; approved for public release.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

The aluminum corrosion protection capabilities of military antifreeze MIL-A-46153 are improved by the addition of silicate and other corrosion inhibitors to its formulation. MIL-A-46153's improvement is shown through the use of standard ASTM laboratory coolant tests.

**14. SUBJECT TERMS**
MIL-A-46153, aluminum protection, engine coolant, heavy duty coolant, silicate, combat/tactical vehicle

**15. NUMBER OF PAGES** 22

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

No. 13614

# Improved Antifreeze for Combat/Tactical Vehicles

| Accesion For | | |
|---|---|---|
| NTIS CRA&I | ☑ | |
| DTIC TAB | ☐ | |
| Unannounced | ☐ | |
| Justification | | |
| By | | |
| Distribution / | | |
| Availability Codes | | |
| Dist | Avail and / or Special | |
| A-1 | | |

## December 1994


By Dwayne Davis
USA Tank Automotive Command
Mobility Technology Center Belvoir
Fuels and Lubricants Division

# Contents



## Tables

# Section 1 Objective and Background

The objective of this program was to improve the performance of the current MIL-A-46153 military antifreeze by changing its formulation. Specifically, the thrust was to improve its aluminum corrosion protection. The current MIL-A-46153 formulation was developed in the 1950's when heavy-duty engines and water pumps were constructed of cast iron, with brass/copper radiators. Today, heavy-duty engine manufacturers are employing aluminum alloys at an ever increasing rate to reduce total engine weight and increase overall engine efficiency. The use of aluminum alloys can be found in radiators, cylinder heads, water pump housings, manifolds, and engine blocks.[1] With this increase of aluminum use among the heavy-duty engine manufacturers, aluminum components are now found in heavy-duty engine systems used to power military vehicles fleets.

The present MIL-A-46153 military antifreeze formulation[2] contains no "aluminum specific" corrosion inhibitors. The performance of the MIL-A-46153 formulation was evaluated in a 1988 field survey[3] involving 100 military installations throughout the United States and abroad. The results of the survey revealed that MIL-A-46153 performs satisfactorily. For instance, 80% of the installations found the current MIL-A-46153 military antifreeze to be an effective product. However, the remaining 20% of the survey participants felt that MIL-A-46153 needed improving, with some suggesting that the current antifreeze provides minimal corrosion protection for aluminum components. In addition to these suggestions, MIL-A-46153 fails the ASTM laboratory test for heat transfer corrosion of aluminum cylinder heads during engine operation, D4340.[4] ASTM guidelines recommend a new coolant pass this test with a value of $1 mg/cm^2$/week or less. The current MIL-A-46153 military antifreeze consistently fails D4340 with values in ranging between 20 to $40 mg/cm^2$/week. Given the repeated failures of the D4340 test, the average results of the survey, and the introduction of aluminum in heavy-duty applications, a program was initiated to address the feasibility of improving the MIL-A-46153 formulation to enable it becoming an effective antifreeze in the future.

# Section 2 Approach

Several commercial antifreeze formulations were examined to determine which inhibitor combinations give the best aluminum protection and general corrosion protection. Both heavy-duty and light-duty, automotive antifreezes were examined. Professionals in the commercial engine antifreeze industry were consulted. In addition, technical papers concerning antifreeze formulations were reviewed.[5,6,7,8] As a guide in developing an improved MIL-A-46153 military antifreeze, target pH and reserve alkalinity (RA) limits were tentatively chosen. For example, various literature sources[9,10,11,12] suggest that moderately alkaline antifreeze solutions (i.e., pH between 8.5 and 10.5) are more conducive for aluminum corrosion protection than acidic solutions (i.e., pH < 6). For the RA or buffer capacity, a high RA similar to the existing MIL-A-46153 was desired because of the several decades of reliable performance this high RA has provided the military's ground fleet.

After experimental formulations were prepared, their pH and RA values were measured as a concentrate and as a 50-50 aqueous solution. If the pH and RA were considered acceptable, additional tests were conducted on each of the candidate experimental formulations. For example, the ASTM glassware corrosion test, (D1384), and a ASTM heat-rejecting surface test (D4340) were conducted to determine the corrosion protection characteristics for each of the formulations. If the candidate formulation successfully passed these two tests, further testing was done to characterize the formulation physically and chemically (e.g., foaming characteristics, boiling point, specific gravity, etc.). If a candidate formulation met all the above criteria, it was selected for final laboratory systems testing and eventual field evaluation.

Fourteen (14) original experimental formulations were prepared. A list of the 14 formulations is shown in Table 1. The mixing procedure consisted of first combining the borax, the antifoam additive, and the ethylene glycol (EG). This mixture was stirred on a hot plate at a temperature between 50° and 60°C in a 4000-mL, heavy-duty beaker until the solution gave a clear appearance. Initially, the first nine (9) formulations were stirred by hand with a stirring rod. For subsequent samples, a hot plate with a magnetic stirrer and a stirring bar were employed because the constant agitation allowed the components to dissolved faster. The total time elapsed during mixing was between 35 to 45 minutes after initial heating began. The remaining inhibitors were combined with the "added water" in a 500-mL beaker. This solution was stirred and heated on a hot plate between 40° and 55°C until the solution became clear. The total time elapsed during mixing was between 25 to 35 minutes after initial heating began. Once the two solutions appeared clear, the contents of the smaller beaker were combined in the larger beaker and the resultant mixture stirred an additional 30 minutes to an hour depending on how fast the solution became clear in appearance.

Table 1. Candidate Formulations (*weight percent*)

| Compound | #1 | #2 | #3 | #4 | #5 | #6 | #7 |
|---|---|---|---|---|---|---|---|
| $Na_2B_4O_7 \cdot 10H_2O$ | 4.0 | 4.0 | 2.0 | 4.0 | 2.0 | 2.0 | 2.0 |
| $Na_3PO_4 \cdot 12H_2O$ | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| $NaNO_2$ | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| $NaNO_3$ | 0.2 | 0.2 | 0.2 | — | — | — | — |
| $Na_2MoO_4 \cdot 2H2O$ | — | — | — | — | — | — | 0.3 |
| NaTT (50%aq) | — | 0.2 | 0.2 | 0.2 | 0.25 | 0.25 | 0.25 |
| DiNaMBT (50%aq) | 0.2 | — | — | — | — | — | — |
| $Na_2SiO_3 \cdot 9H_2O$ | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| NaOH | — | — | — | — | — | 0.2 | — |
| Antifoam | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Added Water | 5.0 | 2.4 | 3.3 | 2.5 | 2.0 | 2.0 | 2.0 |
| Ethylene Glycol | Bal | Bal | Bal | Bal | Bal | Bal | Bal |
| pH Concentrate | 6.6 | 6.4 | 6.4 | 6.5 | 6.6 | 6.8 | 6.8 |
| RA Concentrate,mL | 29.3 | 31.3 | 16.8 | 29.8 | 17.4 | 19.5 | 17.6 |
| pH 50/50 Solution | 7.8 | 7.8 | 7.8 | 7.7 | 8.1 | 8.3 | 8.1 |
| Freeze Point,°F[1] | -25 | -31 | -30 | -32 | -32 | -31 | -32 |

[1] *Freeze point determined with a hand held refractometer as prescribed in ASTM standard method D3321.*

Table 1. Candidate Formulations (*weight percent*) (continued)

| Compound | #8 | #9 | #10 | #11 | #12 | #13 | #14 |
|---|---|---|---|---|---|---|---|
| $Na_2B_4O_7 \cdot 10H_2O$ | 1.1 | 1.1 | 1.1 | — | 1.0 | 2.5 | 2.5 |
| $Na_3PO_4 \cdot 12H_2O$ | 0.6 | 0.6 | — | 0.6 | 0.6 | 0.3 | 0.5 |
| $NaNO_2$ | 0.5 | 0.3 | 0.3 | 0.3 | 0.25 | 0.3 | 0.3 |
| $NaNO_3$ | 0.5 | 0.3 | 0.3 | 0.3 | 0.25 | 0.3 | 0.3 |
| $Na_2MoO_4 \cdot 2H_2O$ | — | — | 0.6 | 1.1 | — | — | — |
| NaTT (50%aq) | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.3 |
| DiNaMBT (50%aq) | — | — | — | — | — | — | — |
| $Na_2SiO_3 \cdot 9H_2O$ | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.5 |
| NaOH | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Antifoam | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Added Water | 2.1 | 2.1 | 2.1 | 2.1 | 2.0 | 2.0 | 2.0 |
| Ethylene Glycol | Bal | Bal | Bal | Bal | Bal | Bal | Bal |
| pH Concentrate | 12.2 | 11.7 | 9.1 | 12.2 | 11.0 | 6.6 | 8.9 |
| RA Concentrate,mL | 23.6 | 17.7 | 12.4 | 11.8 | 16.0 | 23.3 | 27.3 |
| pH 50/50 Solution | 12.2 | 11.7 | 8.9 | 12.1 | 11.0 | 8.2 | 8.5 |
| Freeze Point,°F | -34 | -35 | -40 | -33 | -32 | -33 | -35 |

Of the 14 formulations prepared only four (4) were judged as acceptable experimental candidates for further evaluation. The remaining formulations were eliminated based on their unsatisfactory appearance (e.g., precipitation or cloudiness), low pH, or low RA values. For example, formulation #1 was initially clear and bright, but formed a white crystalline precipitate after sitting several hours. The precipitate was attributed to the copper corrosion inhibitor, disodium 2,5-dimercapto-1,3,4-thiazole (DiNaMBT), being insoluble in ethylene glycol. This was verified by the successful preparation of formulation #2 which substitutes sodium tolytriazole for DiNaMBT and has less added water. No precipitate formed in this solution. The DiNaMBT is a relatively new inhibitor and was tested to determine if it would provide additional benefits compared to the commonly employed copper inhibitors sodium tolytriazole and sodium mercaptobenzothiazole. Formulations #2 through #6, and #9 through #13 did not result in the pH and RA being within the desired ranges. Formulations #7, #8, and #14 were considered acceptable and tested further. Results of the heat-rejecting aluminum tests (i.e., D4340) are shown in Table 2. The results of the three experimental candidate formulation showed a significant improvement over the current MIL-A-46153 formula. The new formulations also meet the ASTM recommended corrosion rate for D4340.

**Table 2. Heat-Rejecting Aluminum Corrosion Test, D4340**

| Sample | #7 | #8 | #14 | Current MIL-A-46153 |
|---|---|---|---|---|
| pH Before Test | 8.6 | 12.1 | 9.1 | 8.3 |
| pH After Test | 8.6 | 11.6 | 8.6 | 8.2 |
| RA Before Test | 4.3mL | 5.8mL | 6.1mL | 7.0mL |
| RA After Test | 3.9mL | 5.0mL | 5.9mL | 7.0mL |
| Corrosion Rate ($mg/cm^2$/week) | +0.8{1} | +1.3 | +0.6 | 29.2 |
| ASTM Recommended Corrosion Rate | 1.0 | | | |

In addition to the D4340 screening test, the glassware corrosion D1384 was also performed on formulation #14. The results are shown in Table 3. The glassware results for formulation #14 were comparable to the current MIL-A-46153 formulation and are within the ASTM recommended weight losses. However, funding constraints prevented the additional glassware corrosion testing of formulations #7 and #8 and final laboratory evaluation of these candidate formulations.

Table 3. Glassware Corrosion Test D1384, weight loss/specimen, mg

| | Copper | Solder | Brass | Steel | Cast Iron | Cast Aluminum |
|---|---|---|---|---|---|---|
| #14 | +3 | 10 | +2 | +1 | 1 | +6 |
| MIL-A-46153 | 1 | 7 | 3 | 2 | 1 | +1 |
| ASTM maximum | 10 | 30 | 10 | 10 | 10 | 30 |

Table 4. MIL-A-46153 Formulation

| Compound | Weight % |
|---|---|
| $Na_2B4O_7 \cdot 10H_2O$ | 4.0 |
| $Na_3PO_4 \cdot 12H_2O$ | 0.3 |
| $NaNO_2$ | — |
| $NaNO_3$ | — |
| NaTT (50%aq) | 0.25 |
| $Na_2SiO_3 \cdot 9H_2O$ | — |
| NaOH | — |
| Antifoam | 0.02 |
| Total Water | 5.0 |
| Ethylene Glycol, min | 77.6 |
| Total vicinal glycols, min | 87.6 |

# Section 3 Conclusions

Because of the loss of technology base resources, this effort could not be completed. However, the program did produce three (3) candidate formulations (i.e., #7, #8, and #14) which could be used to upgrade the current MIL-A-46153 military antifreeze. More extensive laboratory (i.e., D2809 aluminum water pump cavitation test and D2570 simulated service test) are required to verify the performance of these formulations.

While the MIL-A-46153 antifreeze improvement program was being conducted, a parallel effort to develop a less toxic alternative antifreeze was initiated. Development work on this project began in FY93. This effort was part of the Hazardous Waste Minimization Program of the Defense General Supply Center (DGSC) in Richmond, Virginia, and was funded through their Defense Environmental Restoration Account appropriations. The current formulation for MIL-A-46153 uses ethylene glycol (EG) as its base material. Its formulation is given in Table IV. Because of its relatively high toxicity,[13] state and federal regulatory restrictions on EG have increased steadily in recent years.[14] As a result, DGSC requested[15] that this office consider developing a less hazardous antifreeze. For the alternative antifreeze, propylene glycol (PG) was chosen as the less toxic base material.[16] Because of PG's similar chemical characteristics compared to EG, the research and development accomplished during the program to improve MIL-A-46153 will be directly applied to the PG antifreeze effort. For example, PG's slightly different solubility characteristics compared to EG will enable the improved corrosion inhibitor technology that was developed to be transitioned directly to the PG antifreeze study.

# References


1. Truhan Jr., John J. and Hudgens, R. Douglas, "Effect of Nitrate Concentration on Passivation of Aluminum Alloys in Commercial Coolants for Heavy Duty Diesel Engines", *Worldwide Trends in Engine Coolants, Cooling System Materials and Testing*, SP-811, Society of Engineers, Warren, MI, February 1990, pp. 101-117.

2. Military Specification MIL-A-46153C "Single Package, Heavy Duty, Inhibited Ethylene Glycol Military Specification Antifreeze". (5 August 1991)

3. Davis, Dwayne, "Engine Cooling System Survey of Military Antifreeze MIL-A-46153 Field Performance", U.S. Army Belvoir Center Technical Report #2510, U.S. Army Belvoir Research, Development, and Engineering Center, Fort Belvoir, VA, July 1991.

4. ASTM D4340, "Standard Test Method for Corrosion of Cast Aluminum Alloys in Engine Coolants Under Heat-Rejecting Conditions", *Annual Book of ASTM Standards*, Vol. 15.05, ASTM, Philadelphia, PA, 1993, p 160-164.

5. Cessna, J.C., "Problems in The Use of Corrosion Inhibitors in Automobile Engine Cooling Systems", *Materials Protection*, May 1964, pp. 37-41.

6. Hercamp, R.D. and Hudgens, R.D., "Silicate Gelation in Heavy-Duty Diesel Engines Cooling Systems", SAE Paper 852327 presented at the SAE Truck and Bus Meeting and Exposition, Chicago, IL, December 1985.

7. Conley, J.H. and Jamison, R.G., "Research and Development Efforts In Military Antifreeze Formulations", *Engine Coolant Testing: State of the Art, ASTM STP 705*, W.H. Ailor, Ed., American Society for Testing and Materials, 1980, pp. 102-107.

8. Truhan Jr., John J. and Hudgens, R. Douglas, "Effect of Nitrate Concentration on Passivation of Aluminum Alloys in Commercial Coolants for Heavy Duty Diesel Engines", *Worldwide Trends in Engine Coolants, Cooling System Materials and Testing, SP-811*, Society of Engineers, Warren, MI, February 1990, pp. 101-117.

9. Hudgens, Douglas R. and Bugelski, W.G., "Analysis of Coolants from Diesel Engines", *Worldwide Trends in Engine Coolants, Cooling System Materials and Testing, SP-811*, Society of Engineers, Warrendale, PA, 1990, pp. 79-99.

10. Ohkawa, Satoshi, Kawasaki, Titose and Kumagae, Kenji, "A New Antifreeze Coolant for Heavy-Duty Diesel Engines", *Worldwide Trends in Engine Coolants, Cooling System Materials and Testing, SP-811*, Society of Engineers, Warrendale, PA, 1990, pp. 35-46.

11. Vukasovich, Mark S. and Sullivan, Francis J., "Inhibitors and Coolant Corrosivity", *Engine Coolant Testing: Second Symposium, ASTM STP 887*, Roy E. Beal, Ed., American Society for Testing and Materials, Philadelphia, PA, 1986, pp. 86-98.

12. Rowe, L.C., Chance, R.L., and Walker, M.S., "The Development of An Antifreeze Coolant For Aluminum and Cast Iron Engines", GMR-3819, General Motors Research Laboratories, Warren, MI, October 1981.

13. Hercamp, Richard D. and Hudgens, R. Douglas, "Aqueous Propylene Glycol Coolant for Heavy Duty Engines", *Worldwide Trends in Engine Coolants, Cooling System Materials and Testing, SP-811*, Society of Engineers, Warrendale, PA, 1990, pp. 47-77.

14. Zadrozny, A. J., "Propylene Glycol Coolant: A Safer Alternative for Heavy Duty Vehicles", SAE Paper 930473, 1993, pp. 1-2.

15. Meeting, 10 July 1990, Place: Belvoir Research, Development, and Engineering Center (BRDEC), Attendees: Mr. Patrick Doyle, Defense General Supply Center (DGSC), Mr. Walter Mikucki, U.S. Army Construction Engineering Research Laboratory (CERL), Maj Richard Nowinski, Defense Logistics Agency (DLA), Mr. Maurice E. LePera (BRDEC), Dr. Jim Mengenhauser (BRDEC), and Mr. Dwayne Davis (BRDEC), subject: Antifreeze Project at CERL.

16. Memorandum SATBE-FL, dated 20 June 1991, subject: BRDEC Review of CERL Report on Assess Feasibility of Chemicals Identified as Alternatives to Ethylene Glycol Antifreeze.

# Distribution for Report #13614

DEPARTMENT OF THE ARMY

HQDA
1 ATTN DALO TSE
1 ATTN DALO SM
PENTAGON
WASHINGTON DC 20310-0103

CDR AMC
1 ATTN ANCRD S (V FALCHETTA)
1 ATTN AMCRD E
1 ATTN ANCLG MS (COL BRYANT)
1 ATTN AMCLG MT (COL SIMS)
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

TARDEC
1 ATTN AMSTA N
1 ATTN AMSTA R
1 ATTN AMSTA RG
1 ATTN AMCPM ATP
1 ATTN AMSTA UE
1 ATTN AMSTA UG
CDR TACOM
WARREN MI 48397-5000

CDR TACOM
1 ATTN AMSTA FP
1 ATTN AMSTA KA
1 ATTN AMSTA KL
1 ATTN AMSTA MN
1 ATTN AMSTA MT
1 ATTN AMSTA NC
1 ATTN ANSTA GT
1 ATTN AMSTA FNG
1 ATTN AMSTA FR
1 ATTN USMC LNO
1 ATTN AMCPM LAV
1 ATTN AMCPM M1131/M60
1 ATTN AMCPM CCE/SMHE
WARREN MI 48397-5000

PROG EXEC OFFICER
ARMORED SYS MODERNIZATION
1 ATTN SFAE ASH BY
1 ATTN SFAE ASH CV
1 CDR TACOM
WARREN MI 48397-5000

PROG EXEC OFFICER
COMBAT SUPPORT
1 ATTN SFAE CS TVL
1 ATTN SFAE CS TVH
1 ATTN SFAE CS TVH
CDR TACOM
WARREN MI 48397-5000

DIR
ARMY RSCH LAB
1 ATTN AMSRL CP PW
2800 POWDER HILL RD
ADELPHIA MD 20783-1145

VEHICLE PROPULSION DIR
1 ATTN AMSRL VP (MS 77 12)
NASA LEWIS RSCH CTR
21000 BROOKPARX RD
CLEVELAND OH 44135

CDR ARMY AMCCOM
1 ATTN AMSNC MA
1 ATTN AMXEN U (BEDTRAM)
ROCK ISLAND IL 61299-6000

CDR APC
1 ATTN SATPC Q
1 ATTN SATPC QE (BLDG 85 3)
NEW CUMBERLAND PA 17070-5005

1 PETROL TEST FAC WEST
BLDG 247 TRACEY LOC
DDRW
P O BOX 96001
STOCKTON CA 95296-0960

CDR ARMY TECOM
1 ATTN AMSTE TA R
1 ATTN AMSTE TC D
1 ATTN AMSTE EQ
APG MD 21005-5006

PROJ MGR PETROL WATER LOG
1 ATTN AMCPM PWL
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

PROJ MGM MOBILE ELEC PWR
1 ATTN AMCPM MEP
1 7798 CISSNA RD STE 200
SPRINGFIELD VA 22150-3199

CDR FORSCOM
1 ATTN AFLG TRS
FT MCPHERSON GA 30330-6000

CDR
ARMY COMBINED ARMS SPT CMD
1 ATTN ATCL CD
1 ATTN ATCL MS
1 ATTN ATCL MRD (D GUNNELS)
FT LEE VA 23801-6000

CDR ARMY INF SCHOOL
1 ATTN ATSH CD
1 ATTN ATSH AT
FT BENNING GA 31905-5000

CDR ARMY ENGR SCHOOL
1 ATTN ATSE CD
FT LEONARD WOOD MO 65473-5000

CDR ARMY ORDN CTR
1 ATTN ATSL CD CS
APG MD 21005

CDR ARMY CSTA
1 ATTN STECS EN
1 ATTN STECS LI
1 ATTN STECS AE
1 ATTN STECS AA
1 ATTN STECS EF (R GOUAND)
1 ATTN STECS EE (H GALLIFORD)
1 ATTN STEAP SH EE (M WORSHAM)
APG MD 21005-5059

CDR ARMY YPG
1 ATTN STEYP HT TL N
YUMA AZ 85365-9130

CDR ARMY CERL
1 ATTN CECER EN
P O BOX 9005
CHAMPAIGN IL 61826-9005

CDR I CORPS AND FT LEWIS
1 ATTN AFZH CSS
1 ATTN AFZH DEQ (D POWERS)
1 ATTN AFZH DEQ (TROUT)
FT LEWIS WA 98433-5000

CDR
RED RIVER ARMY DEPOT
1 ATTN SDSRR M
1 ATTN SDSRR Q
1 ATTN SDSRR QA TS (A HOEHN)
TEXARKANA TX 75501-5000

CDR 6TH ID (L)
1 ATTN APUR LG N
1060 GAFFNEY RD
FT WAINWRIGHT AK 99703

**DEPARTMENT OF THE NAVY**

CDR
NAVAL SEA SYSTEMS CMD
1 ATTN SEA 03M3
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

CDR
NAVAL SURFACE WARFARE CTR
1 ATTN CODE 63
1 ATTN CODE 632
1 ATTN CODE 859
3A LEGGETT CIRCLE
ANNAPOLIS MD 21401-5067

1 CDR
NAVAL PETROLEUM OFFICE
CAMERON STA T 40
5010 DUKE STREET
ALEXANDRIA VA 22304-6180

**DEPARTMENT OF THE NAVY/US MARINE CORPS**

HQ USMC
1 ATTN LPP
WASHINGTON DC 20380-0001

1 PROG NCR COMBAT SER SPT
MARINE CORPS SYS CMD
2033 BARNETT AVE STE 315
QUANTICO VA 22124-5080

1 PROG MGR GROUND WEAPONS
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

1 PROC NCR ENGR SYS
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

CDR
MARINE CORPS SYS CMD
1 ATTN SSE
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5010

CDR
BLOUNT ISLAND CMD
1 ATTN CODE 922/1
5880 CHANNEL VIEW BLVD
JACKSONVILLE FL 32226-3404

CDR
MARINE CORPS LOGISTICS BA
1 ATTN CODE 837
814 RADFORD BLVD
ALBANY GA 31704-1128

1 CDR
2ND MARINE DIV
PSC BOX 20090
CAMP LEJEUNNE NC 28542-0090

1 CDR
1ST MARINE DIV
CAMP PENDLETON CA 92055-5702

**DEPARTMENT OF AIR FORCE**

HQ USAF/LGTV
1 ATTN VEH EQUIP/FACILITY
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

1 AIR FORCE HEEP MGMT OFC
615 SHSQ/LGTY MEEP
201 BISCAYNE DR STE 2
ENGLIN AFB FL 32542-5303

1 5A ALC/SFT
1014 ANDREWS RD STE 1
KELLY AFB TX 78241-5603

1 WR ALC/LVRS
225 OCNULGEE CT
ROBINS AFB GA 31098-1647

**DEPARTMENT OF DEFENSE**

DIRDLA
1 ATTN DLA NNDI
1 ATTN DLA MNSB
CAMERON STA
ALEXANDRIA VA 22304-6100

CDR
DEFENSE GEN SUPPLY CTR
1 ATTN DGSC SSA
1 ATTN DGSC SSC (W SMITH)
1 ATTN DGSC STAC (C MYERS)
8000 JEFFERSON DAVIS HWY
RICHMOND VA 23297-5678

12 DEFENSE TECH INFO CTR
CAMERON STATION
ALEXANDRIA, VA 22314

20 MOBILITY TECH CENTER BELVOIR
ATTN AMSTA RBF
FORT BELVOIR, VA 22060

1 MDW DESK LOG
BLDG 17 DR 10
ATTN L FIORENTINO
CAMERON STATION
ALEXANDRIA VA 22304

1 62 TRNS LGTM
761 BATTERY RD BLDG 779
ATTN SGT TILLMANN
MCHORD AFB WA 98438-1127

1 US ARMY CORP OF ENGRS
ATTN CAMM OP R
PO BOX 2288
MOBILE AL 36628-0001

1 EDGAR POE
NATL RES ENVRMT AFFR
BLDG 1059 MARINE CORP
TWENTY NINE PALMS
CA 92278-5000

1 857TH CES DEVE
BLDG 445
MINOT AFB ND 58705-5000

1 MARINE CORP LOG BASE
NATL RES ENVRL OFFICE
ATTN AL HARGROVE
CODE 560
ALBANY GA 31704

1 DEH
ENVRL DIVISION
ATTN ATZR E (SCOTT)
FT SILL OK 73503-5100

1 MMC (MSWSES)
FRANCISO TADAY
SAFETY CODE 0009
PORT HUENEME CA 93043

1 DEH
ATTN BRMD (L CLEMONS)
FT DRUM NY 13602-5097

1 HQ USAF CEV
BOLLING AFB
ATTN CPT J HROMOWYK
WASHINGTON DC 20332-5000

1 SAFETY LINE MAGAZINE
CODE 722 EDITOR
RAE MAGILL
NAVAL SAFETY CTR NAS
NORFOLK VA 23511

1 HQ MACK LEMSB
ATTN SGT SHAW
SCOTT AFB IL 62225-5001

1 US ARMY FT GREELEY
ATTN APVR FG DE (ROSSI)
SEATTLE WA 98733

1 NATNL GUARD INDIANA
2002 S HOLT RD
ATTN MD FE EN (CPT ORE)
INDIANAPOLIS IN
46241-0326

1 LETTERKENNY ARMY DEPOT
ENVRL MAN DIV BLDG 363
ATTN SDSLE ENE (UPSTAIN)
CHAMBERSBURG PA 17201

1 SUPPLY & SERVICE DIV
ATTN ATZC ISL S
FT BLISS TX 79916

1 III CORP G-4
ATTN AFTZ GL (CPT YOCKUM)
FT HOOD TX 76546

1 NWR DEPT
NAVAL AIR STATION
ATTN S KOWALSKI
FALLON NV 09406-5000

1 ADJT GENL IOWA
CAMP DODGE
ATTN AGIA FAC E (GAICH)
7700 BEAVER DR
JOHNSTOWN IA 50131

1 MAJ D CORNELL
ATTN OC LAC EMW
TINKER AFB OK 73145

1 CDR 10TH MOUNTAIN DIV
DEH ENVRL OFFICE
ATTN AFZX DH E
FT DRUM NY 13602-5000

1 JILL RUSH
436 CES DEEV
DOVER AFB DE 19902-5516

1 MIKE MARKER
2750TH ABW EMC
WRIGHT PATTERSON AFB OH
45433-5000

1 ARMY RES MAIT SUP SHOP
ATTN AMSA5 (F ELLESER)
2800 CRESTLINE RD
FT WORTH TX 76107

1 ERNEST EDDY
HHC 8TH USA ARMY
PSC303 PO BOX 78
APO AP 96205-0078

1 CDR HHB 1ST BATTLN
43RD ADA
ATTN BMO
FT BLISS TX 79916

1 CDR HHB 1ST BATTLN
62ND TRANS CO
FT BLISS TX 79916

1 CDR NEW CUMBERLAND ARMY
DEP DIR MAINT
ATTN SDSNC M
NEW CUMBERLAND PA 17070

1 MK1 BURNS
CGSTA BURLINGTON
DEPOT ST
BURLINGTON VT 05401

1 BILL CONN
HQ 18TH AIRBORN CORP
FT BRAGG DEH
ATTN AFZA DEDV
FT BRAGG NC 28307-5000

1 CHIEF NG BUREAU
ATTN NGB ARL SM (MADDEN)
ARLINGTON HALL STATION
BLDG T-420
ARLINGTON VA 22304-1382

1 BRH MED CLINIC
INDRL HYGNT
MARINE CORP LOG BASE
BARSTOW CA 92311

1 MSG M KRIZ
5TH MAINT SQUAD
MINOT AFB ND 58704

1 LESTER DZIUK
ATTN SA LAC SFTT
KELLY AFB TX 78241-5000

1 DAVID DAVIS
US ARMY ENVL HYG AGY
WASTE DISPOSAL
APG MD 21010-5422

1 JOHN SHIMP
DEH BLDG 408
ENVRL & NATL RES DIV
FT FILEY KS 66442-6016

1 CDR ANNISTON ARMY DEPOT
DIR MAINT
ATTN SDSAN M
ANNISTON AL 36201-5000

1 MSG T SMITH
60TH MAW MASE
TREVIS AFB CA 94535

1 PEGGY HARLOWE
CONN NG
360 BROAD ST
HARTFORD CT 06805-3795

1 VINCENT TUNG
8403 LEE HWY
MERRIFIELD VA 22080-8101

1 LTC MARK HAGUE
COLORADO NATL GUARD
6848 REVERE PARKWAY
ENGLEWOOD CO 80112

1 WASHINGTON ST MIL DEPT
ATTN FMO ENGR
G MATTHEWS
BLDG 33 CAMP MURRAY
TACOMA WA 98430-5054

1 DAVE ELLIOT
SAN ANTONIO ALC
ATTN LDPT
KELLY AFB TX 78241

1 CDR LETTERKENNY ARMY DEP
ATTN SDSLE MME (K GULYAS)
BLDG 1C
CHAMBERSBURG PA
17201-4150

1 JIM PARKER
NC DEPT TRANS
EQUIP UNIT
4809 BERYLE ST
RALEIGH NC 27600

1 KEN WALLER
AEROSPACE FUELS LAB
C BLDG 1
10 PARK AVE
MUKILTEO WA 78275

1 CDR TOOELE ARMY DEPOT
DIR MAINT
ATTN SDSTE M
TOOELE UT 84074-5011

1 CDR USCG GRP UPR MISS
221 MISSISSIPPI DR
ATTN CHIEF CANDLER
KEOKUK IA 52632

1 NICKS KNOPES
WR ALC LZEC
ROBBINS AFB GA 31098

1 CDR TOBYHANNA ARMY DEPOT
ATTN PAT TIERNEY
TOBYHANNA PA 18466-5075

1 NSS FACLTY
NEW LONDON CONN
NAVSEA OFF (KING)
PO BOX 300
GROTON CT 06349

1 AIR NATL GUARD
ATTN ANGRC LGMSE (VILLA)
3500 FETCHT AVE
ANDREWS AFB MD 20331-5151

1 CIVIL ENGR SUPP
ATTN S JOHNSON
CODE 15741
PORT HUNEME CA
93043-5000

1 ADJ GENRL PENN
US PRPTY OFF FIS PENN
ATTN CW2 R SCHAFFER
DEPY MILITARY AFFRS
ANNVILLE PA 17003-5002

1 HQ FT DEVENS
ATTN AFZD EM (C WILLIAMS)
PO BOX 19
FT DEVENS MA 01433

1 LETTERKENNY ARMY DEPOT
ENVRL MAN DIV BLDG 363
ATTN SDSLE ENE (UPSTAIN)
CHAMBERSBURG PA 17201

1 USALAL
ATTN AMXLA C E DV
K DESAUSPELS
FT DEVENS MA 01433-5880

1 FACLTYS ENGRG
LTC HURELY
US CG TRNG CTR
CAPE MAY NJ 08204

1 WYOMING ARMY NG
SURFACE MAINT
PO BOX 1709
ATTN CPT SHEPPARD
CHEYENNE WY 02003-1709

1 US ARMY CORP ENGRS
LA CLAIR BASE PLANT
ATTN OD MP (J WILSON)
PO BOX 2004
ROCK ISLAND IL 61204-2004

1 CORKY CROVATO
KASCO FUEL MAINT
4481 BEECH RD
TEMPLE HILLS MD 20748

1 FPPF CHEMICAL CO
ROBERT MILLER
32 MONROE AVE
ROSELAND NJ 07068

1 FINISH THOMPSON INC
PETER SCANTLEBURY
921 GREENGARDEN RD
ERIE PA 16501-4478

1 LTC CHARLES SMITH
HQ USMC
CODE LFS-2
WASHINGTON DC 20380

1 USA ARMY LOG ASS OFFC
ATTN AMXLA C E JK
AL NELSON
PO BOX 10010
FT JACKSON SC 29207-0010

1 TOOELE ARMY DEPOT
ATTN SDSTE PAQ (D COX)
TOOELE UT 84074

1 TOOELE ARMY DEPOT
BLDG 113
ATTN R RAFMUSSEN
TOOELE UT 84074

1 JENS KNUDSEN
ATTN GC LGTM
TOOLEY AFB GREENLAND
12 SWSAPO AE
09704-5000

1 RENE WIBE
CHEMIST
BG PRODUCTS INC
701 S WICHITA ST
WICHITA KS 67213

1 RASCO
GERALD ESKELUND CEP
1635-3 WOODSIDE DR
WOODBRIDGE VA 22191

1 MARVIN LEATH ASS
ROBERT NOVOGRATZ
SUITE 300
ONE MASS AVE NW
WASHINGTON DC 20001

1 FIRST BRANDS CORP
COOLANT DEVE
PETER WOYCIESJES
55 FEDERAL RD
DANBURY CT 06810

1 GARY SNYDER
615 SMSQ LGTV MEEP
201 BISCAYNE RD SUITE 2
EGLIN AFB FL 32542-5303

1 DEF FUELS OFF ALASKA
6920 12TH ST
ATTN FUELS LAB (SOHLBURG)
ELMENDORF AFB ALASKA
99506-2570

1 AMC INSTLNS SER ACT
ATTN AMXEN U (BEDTRAM)
ROCK ISLAND IL 61299

1 CDR DUGWAY PRVG GRD
ATTN EN MM (JACK DAVIS)
DUGWAY UT 84022

1 WYNN OIL CO
TECH SERVS
JIM BAYLOR
1151 W FITTH ST
AZUZA CA 91702

1 COOPER ENTERPRISES
BOB SWEENEY
2122 COUNTRY CLUB DR
SUITE 280
CARROLLTON TX 75006

1 FINISH THOMPSON INC
PRESIDENT CEO
H DAVID BOWES
921 GREENGARDEN RD
ERIE PA 16501-1591

1 KLEER FLO CO
PRESIDENT
WALLACE HILGREN
15151 TECHNOLOGY DR
EDEN PRAIRIE MN 55344

1 188 FG LGTM
4850 LEIGH AVE
ATTN SMS MITCHEL
FT SMITH AR 72903

1 NELS PALM
AMER FLUID TECH
9 FLETCHER ST
CHELMSFORD MA 01824

1 89TH TRANS LGTM
3427 PENN AVE
ATTN SSGT C DOLLAR
ANDREWS AFB MD 20331-5005

1 ARMY PET CTR
ATTN PET READS DIV (WARD)
NEW CUMBERLAND PA
17070-5008

1 NAVAL WARFARE CTR
DEPT CODE SR 41
ATTN WALT KOEHLER
LAKEHURST NJ 08733

1 ALBERT MORALES
ATTN LDEE SALAC
KELLY AFB
SAN ANTONIO TX 78241

1 RALPH PHIIPPS
NREA BRANCH
3040 MCCAWLEY AVE
QUANTICO VA 22134

1 TOM HACKNEY
PUBLIC WORKS DEPT
TRANS DIV CODE W80
NAVAL SURF WARFARE CTR
DALHGRAN VA 22448-5000

1 KANSAS ARMY NATL GUARD
CSMS
ATTN D CRUMPTON
131 W 127TH ST
TOPEKA KS 66611-1159

1 GARY AKASAKI
DIR PUBLIC WORKS
ENVRL OFF USASCH
FT CHESTER HI 96858-5000
STOP 253

1 ERNIE BRANDT
DIR LOG MAINT DIV
FT RICHARDSON AK 99505

1 ADJ GENL PENN
ATTN SSCMO (REMMINGER).
BLDG 9-68
FT INDIANTOWN GAP
ANNVILLE PA 17003-5002

1 NATL GUARD BUREAU
ATTN NGB ZPF (LTC SMITH)
2500 ARMY PENTAGON
WASHINGTON DC 20310-2500

1 USPNFO
ATTN DSJ PC (REDHORSE)
BLDG 7100 CAMP ROBINSON
NORTH LITTLE ROCK AR
72118-2200

1 MANNY RUYZ
49 CES CEV
550 TAVOSA AVE
HOLLOMAN AFB NM
88330-8450